SECTION 6-05, PILING
September 30, 1996

Section 6-05 is revised to read:

6-05.1 Description

This work consists of furnishing and driving piles (timber, precast concrete, cast-in-place concrete, and steel) of the sizes and types the Contract or the Engineer require. This work also includes cutting off or building up piles when required. In furnishing and driving piles, the Contractor shall comply with the requirements of this section, the Contract, and the Engineer.

6-05.2 Materials

Materials shall meet the requirements of the following sections:

Reinforcing Steel	9-07
Prestressing Steel	9-07.10
Timber Piling	9-10.1
Concrete Piling	9-10.2
Cast-in-Place Concrete Piling	9-10.3
Steel Piling	9-10.5
Steel Pile Tips and Shoes	9-10.6

6-05.3 Construction Requirements

6-05.3(1) Piling Terms

Concrete Piles Concrete piling may be precast, precast-prestressed, or cast-in-place in steel casings driven to the minimum load-bearing capacity called for in the Contract.

Steel Piles Steel piles may be open-ended or closed-ended pipe piles, or H-piles.

Overdriving Over-driving of piles occurs when the bearing capacity calculated from the equation in Section 6-05.3(12), or the wave equation if applicable, exceeds the nominal capacity required in the Contract in order to reach the minimum tip elevation specified in the Contract, or as required by the Engineer.

Maximum Driving Resistance The maximum driving resistance is either the pile ultimate bearing capacity, or ultimate bearing capacity plus overdriving to reach minimum tip elevation as specified in the Contract.

Wave Equation Analysis Wave equation analysis is an analysis performed using the wave equation analysis program (WEAP) with a version dated 1987 or later. The wave equation may be used as specified herein to verify the Contractor’s proposed pile driving system. The pile driving system includes, but is not necessarily limited to, the pile, the hammer, the helmet, and any cushion. The wave equation may also be used by the Engineer to determine pile driving criteria as may be required in the Contract.

Ultimate Bearing Capacity Ultimate bearing capacity refers to the vertical load carrying capacity (in units of force) of a pile as determined by the equation in Section 6-05.3(12), the wave equation analysis, pile driving analyzer and CAPWAP, static load test, or any other means as may be required by the Contract, or the Engineer.

Allowable Bearing Capacity Allowable bearing capacity is the ultimate bearing capacity divided by a factor of safety. The Contract may state the factor of safety to be used in calculating the allowable bearing capacity from the ultimate bearing capacity. In the absence of a specified factor of safety, a value of three (3) shall be used.

Rated Hammer Energy The rated energy represents the theoretical maximum amount of gross energy that a pile driving hammer can generate. The rated energy of a pile driving hammer will be stated in the hammer manufacturer’s catalog or specifications for that pile drive hammer.

Developed Hammer Energy The developed hammer energy is the actual amount of gross energy produced by the hammer for a given blow. This value will never exceed the rated hammer energy. The developed energy may be calculated as the ram weight times the drop (or stroke) for drop, single acting hydraulic, single acting air/steam, and open-ended diesel hammers. For double acting hydraulic and air/steam hammers, the developed hammer energy shall be calculated from ram impact velocity measurements or other means approved by the Engineer. For closed-ended diesel hammers, the developed energy shall be calculated from the measured bounce chamber pressure for a given blow. Hammer manufacturer calibration data may be used to correlate bounce chamber pressure to developed hammer energy. For a single acting diesel hammer the developed energy is determined using the blows per minute.

Transferred Hammer Energy The transferred hammer energy is the amount of energy transferred to the pile for a given blow. This value will never exceed the developed hammer energy. Factors that cause transferred hammer energy to be lower than the developed hammer energy include friction during the ram downstroke, energy retained in the ram and helmet during rebound, and other impact losses. The transferred energy can only be measured directly by use of sensors attached to the pile. A pile driving analyzer (PDA) may be used to measure transferred energy.

Pile Driving Analyzer A pile driving analyzer (PDA) is a device which can measure the transferred energy of a pile driving system, the compressive and tensile stresses induced in the pile due to driving, the bending stresses induced by hammer mis-alignment with the pile, and estimate the ultimate capacity of a pile at a given blow.

Pile Driving System The pile driving system includes, but is not necessarily limited to, the hammer, leads, helmet or cap, cushion and pile.

Pile Driving Refusal Pile driving refusal is defined as 15 blows per inch for the last 4 inches of driving. This is the maximum blow count allowed during overdriving.

Minimum Tip Elevation The minimum tip elevation is the elevation to which the pile tip must be driven. Driving deeper in order to obtain the required bearing may be required.

6-05.3(2) Ordering Piling

The Contractor shall order all piling (except cast-in-place concrete and steel piles) from an itemized list the Engineer will provide. This list, showing the number and lengths of piles required, will be based on test-pile driving (or other) data. The list will show lengths below the cutoff point. The Contractor shall supply (and bear the cost of supplying) any additional length required for handling or driving.

The Contractor shall assume all responsibility for buying more or longer piles than those shown on the list provided by the Engineer. All piles purchased on the basis of the Engineer's list but not used in the finished structure shall become the property of the Contracting Agency. The Contractor shall deliver these as the Engineer directs. The Contractor shall keep pile cutoffs that are 8 feet or under and any longer ones the Contracting Agency does not require.

When ordering steel casings for cast-in-place concrete and steel piling, the Contractor shall base lengths on information derived from driving test piles and from subsurface data. The Contractor shall also select the wall thickness of steel piles or steel casings for cast-in-place piles which will be necessary to prevent damage during driving and handling. The selection of wall thickness for steel piles or steel casings shall also consider the effects of lateral pressures form the soil or due to driving of adjacent piles. Steel piles and steel casings must be strong and rigid enough to resist these pressures without deforming or distorting. The Contractor shall select the wall thickness based on information derived from test piles, subsurface data and/or wave equation analysis. Wave equation analysis is required prior to ordering piling for piles with specified ultimate bearing capacities of 300 tons or greater. If a wave equation analysis is performed, the Contractor shall base the selection of wall thickness on the maximum driving resistance identified in the Contract to reach the minimum tip elevation, if the maximum driving resistance is greater than the specified ultimate bearing capacity and if a minimum tip elevation is specified. The wave equation analysis shall be submitted by the Contractor as required in Section 6-05.3(9)A. The Engineer will not supply any list for piling of these types.

The Contractor shall obtain the Engineer's approval of pile dimensions before any steel casings or steel piles are ordered or shipped.

6-05.3(3) Manufacture of Precast Concrete Piling

Precast concrete piles shall consist of concrete sections reinforced to withstand handling and driving stresses. These may be reinforced with deformed steel bars or prestressed with steel strands. The Plans show dimensions and details. If the Plans require piles with square cross-sections, the corners shall be chamfered 1 inch.

13 inch diameter precast or prestressed piles shall meet the requirements of Standard Plans E-4.

16 inch and 18 inch diameter precast-prestressed piles shall meet the requirements of Standard Plans E-4a.

Temporary stress in the prestressing reinforcement of prestressed piles (before loss from creep and shrinkage) shall be 70 percent of the minimum ultimate tensile strength. (For short periods during manufacture, the reinforcement may be overstressed to 80 percent of ultimate tensile strength if stress after transfer to concrete does not exceed 70 percent of that strength.)

Prestressed concrete piles shall have a final (effective) prestress of at least 700 psi.

Unless the Engineer approves splices, all piles shall be full length.

The Contracting Agency intends to perform Quality Assurance Inspection. By its inspection, the Contracting Agency intends only to facilitate the work and verify the quality of that work. This inspection shall not relieve the Contractor of any responsibility for identifying and replacing defective material and workmanship.

6-05.3(3)A Casting and Stressing

Reinforcing bars, hoops, shoes, etc. shall be placed as shown in the Contract , with all parts securely tied together and placed to the specified spacings. No concrete shall be poured until all reinforcement is in place in the forms.

The Contractor shall perform quality control inspection. The manufacturing plant for precast concrete piling shall be certified by the Precast/Prestressed Concrete Institute’s Plan Certification Program for the type of precast piling to be produced and shall be approved by WSDOT as a Certified Precast Concrete Fabricator prior to start of production. WSDOT Certification will be established or renewed during the annual precast plant review and approval process.

Prior to the start of production of the piling, the Contractor shall advise the Engineer of the production schedule. The Contractor shall give the Inspector safe and free access to the work. If the Inspector observes any nonspecification work or unacceptable quality control practices, the Inspector will advise the plant manager. If the corrective action is not acceptable to the Engineer, the piling(s) will be rejected.

In casting concrete piles, the Contractor shall:

1. Cast them either vertically or horizontally;

2. Use metal forms (unless the Engineer approves otherwise) with smooth joints and inside surfaces that can be reached for cleaning after each use;
3. Brace and stiffen the forms to prevent distortion;
4. Place concrete continuously in each pile, guarding against horizontal or diagonal cleavage planes;
5. Ensure that the reinforcement is properly embedded;
6. Use internal vibration around the reinforcement during concrete placement to prevent rock pockets from forming; and
7. Cast test cylinders with each set of piles as concrete is placed.

Forms shall be metal and shall be braced and stiffened to retain their shape under pressure of wet concrete. Forms shall have smooth joints and inside surfaces easy to reach and clean after each use. That part of a form which will shape the end surface of the pile shall be a true plane at right angles to the pile axis.

Each pile shall contain a cage of nonprestressed reinforcing steel. The Contractor shall follow the Contract in the size and location of this cage, and shall secure it in position during concrete placement. Spiral steel reinforcing shall be covered by at least 1 1/2 inches of concrete measured from the outside pile surface.

Prestressing steel shall be tensioned as required in Section 6-02.3(25)C.

The Plans specify tensioning stress for strands or wires. Tension shall be measured by jack pressure as described in Section 6-02.3(25)C. Mechanical locks or anchors shall temporarily maintain cable tension. All jacks shall have hydraulic pressure gauges (accurately calibrated and accompanied by a certified calibration curve no more than 180 days old) that will permit stress calculations at all times.

All tensioned piles shall be pretensioned. Post-tensioning is not allowed.

The Contractor shall not stress any pile until test cylinders made with it reach a compressive strength of at least 3,300 psi.

6-05.3(3)B Finishing

As soon as the forms for precast concrete piles are removed, the Contractor shall fill all holes and irregularities with 1:2 mortar. That part of any trestle pile that will be underground or below the low-water line and all parts of any pile to be used in salt water or alkaline soil shall receive only this mortar treatment. That part of any trestle pile that will show above the ground or water line shall be given a Class 3 finish as described in Section 6-02.3(14)C.

6-05.3(3)C Curing

Precast Concrete Piles

The Contractor:

1. Shall keep the concrete continuously wet with water after placement for at least ten days with Type I or II Portland cement or at least three days with Type III.

2. Shall remove side forms no sooner than 24 hours after concrete placement, and then only if the surrounding air remains at no less 50°F for five days with Type I or II Portland cement or three days with Type III.

3. May cure precast piles with saturated steam or hot air, as described in Section 6-02.3(25)D, provided the piles are kept continuously wet until the concrete has reached a compressive strength of 3,300 psi.

Precast-Prestressed Concrete Piles

These piles shall be cured as required in Section 6-02.3(25)D.

6-05.3(4) Manufacture of Steel Casings for Cast-in-place Concrete Piles

The diameter of steel casings shall be as specified in the Contract. Spiral welded steel pile casings are not allowed for steel pile casings greater that 24-inch diameter. A full penetration groove weld with a maximum $^{1}/_{16}$-inch offset between welded edges is required.

6-05.3(5) Manufacture of Steel Piles

Steel piles shall be made of rolled steel H-pile sections, steel pipe piles, or of other structural steel sections described in the Contract.

6-05.3(6) Splicing Steel Casings and Steel Piles

The Engineer will normally permit steel piles and steel casings for cast-in-place concrete piles to be spliced. But in each case, the Contractor must obtain approval on the need and the method for splicing. Welded splices shall be spaced at a minimum distance of 10 feet. Only welded splices will be permitted.

Splice welds shall comply with Section 6-03.3(25) and AWS D1.1 Structural Welding Code. Splicing of steel piles shall be performed in accordance with an approved weld procedure. The Contractor shall submit a weld procedure to the Engineer for approval prior to welding. For ASTM A252 material, mill certification for each lot of pipe to be welded shall accompany the submittal.

Weld splicing of steel casings for cast-in-place concrete piles shall be the Contractor's responsibility. Casings which collapse or are not watertight, shall be replaced at the Contractor's expense.

Steel casing joints shall not be offset more than 1/16 inch.

6-05.3(7) Storage and Handling

The Contractor shall store and handle piles in ways that protect them from damage.

6-05.3(7)A Timber Piles

Timber piling shall be stacked closely and in a manner to prevent warping. The ground beneath and around stored piles shall be cleared of weeds, brush, and rubbish. Piling shall be covered against the weather if the Engineer requires it.

The Contractor shall take special care to avoid breaking the surface of treated piles. They shall be lifted and moved with rope or chain slings (without the use of cant dogs, peaveys, hooks, or pike poles). If timber piles are rafted, any attachments shall be within 3 feet of the butts or tips. Any surface cut or break shall be brushed with two coats of creosote oil and covered with an approved roofing asphalt. The Engineer may reject any pile because of a cut or break.

6-05.3(7)B Precast Concrete Piles

The Contractor shall not handle any pile until test cylinders made with the same batch of concrete as the pile reach a compressive strength of at least 3,300 psi.

Storing and handling methods shall protect piles from fractures by impact and undue bending stresses. Handling methods shall never stress the reinforcement more than 12,000 psi. An allowance of twice the calculated load shall be made for impact and shock effects. The method of lifting the piles shall be submitted to the Engineer for approval. The Contractor will take extra care to avoid damaging the surface of any pile to be used in sea water or alkaline soil.

6-05.3(7)C Steel Casings and Steel Piles

The Engineer will reject bent, deformed, or kinked piles which cannot be straightened without damaging the metal.

6-05.3(8) Pile Tips and Shoes

The Contracting Agency prefers that timber piles be driven with squared ends. But if conditions require, they may be shod with metal shoes. Pile tips and shoes shall be securely attached to the piles in accordance with the manufacturer's recommendations.

Where called for in the Contract, conical steel pile tips shall be used when driving steel casings. The tips shall be inside fit, flush-mounted such that the tip and/or weld bead does not protrude more than 1/16-inch beyond the nominal outside diameter of the steel casing.

If conical tips are not specified, the lower end of each casing shall have a steel driving plate that is thick enough to keep the casing watertight and free from distortion as it is driven. The diameter of the steel driving plate shall not be greater than the outside diameter of the steel casing.

Where called for in the Contract, inside-fit cutting shoes shall be used when driving open-ended steel piles. The cutting shoes shall be flush-mounted such that the shoe and/or weld bead does not protrude more than 1/16-inch beyond the nominal outside diameter of the steel pile. The cutting shoe shall be of an inside diameter at least 0.75-inch less than the nominal inside diameter of the steel pile.

Pile tips or shoes shall be of a type denoted in the Qualified Products List. If pile tips or shoes other than those denoted in the Qualified Products List are proposed, the Contractor shall submit shop drawings of the proposed pile tip along with design calculations, specifications, material chemistry and installation requirements, to the Engineer for approval. The Contractor shall also submit evidence of a pile driving test demonstrating suitability of the proposed pile tip. The test shall be performed in the presence of the Engineer or an acceptable independent testing agency. The test shall consist of driving a pile fitted with the proposed tip. The pile shall be located outside the proposed foundation limits if the pile cannot be visually inspected (see Section 6-05.3(11)F). The pile shall be driven to a depth sufficient to develop the required bearing capacity as called for in the Contract, in ground conditions determined to be equivalent to the ground conditions at the project site. For closed-ended casings or piles, the pile need not be removed if, in the opinion of the Engineer, the pile can be inspected for evidence of damage to the pile or the tip. For open-ended steel casings or piles, timber piles or H-piles, the pile shall be removed for inspection.

6-05.3(9) Pile Driving Equipment

6-05.3(9)A Pile Driving Equipment Approval

Prior to driving any piles, the Contractor shall submit to the Engineer for approval the details of each proposed pile driving system. The pile driving system shall meet the following minimum requirements for the various combinations of hammer type and pile type. These requirements are minimums and may need to be increased in order to ensure that the required bearing capacity can be achieved, that minimum tip elevations can be reached, and to prevent pile damage.

The Contractor shall submit a wave equation analysis for all pile driving systems used to drive piling with required ultimate bearing capacities of 300 tons or greater. The wave equation analysis shall be performed by, and bear the stamp of, a civil engineer licensed in the State of Washington. The wave equation analysis shall be performed in accordance with the requirements of this section and the user's manual for the program. The wave equation analysis shall verify that the pile driving system proposed does not produce stresses greater than 90 percent of the yield stress for steel piles, or steel casings for cast-in-place concrete piles. For prestressed concrete piles, the allowable driving stress shall be $3\sqrt{f'_c}$ plus prestress in tension, and $0.85f'_c$ minus prestress in compression. The wave equation shall also verify that the pile driving system does not exceed the refusal criteria at the depth of penetration anticipated for achieving the required ultimate bearing capacity and minimum tip elevation. Furthermore, the wave equation analysis shall verify that at bearing, the maximum driving resistance is 100 blows per foot or less. Unless otherwise specified in the Contract, or directed by the Engineer, the following default values shall be used as input to the wave equation analysis program:

Output option (IOUT)	0
Factor of safety applied to (R_{ult})	1.0
Type of damping	Smith
Residual stress option	No

R_{ult} is equal to the maximum driving resistance for the pile

HAMMER EFFICIENCIES:	For Analysis of Driving Resistance	For Analysis of Driving Stresses
Single acting diesel hammers	0.72	0.84
Closed-ended diesel hammers	0.72	0.84
Single acting air/steam hammers	0.60	0.70
Double acting air/steam hammers	0.45	0.53
Hydraulic hammers or other external combustion hammers having ram velocity monitors that may be used to assign an equivalent stroke.	0.85	1.00

Within 15 working days after the Engineer receives the submittal, the Contractor will be notified of the Engineer's acceptance or rejection. If the Contractor wishes to change the pile driving system after the Contractor's proposed system has been approved, the system must be submitted for approval to the Engineer, and up to an additional 10 working days for approval will be required.

6-05.3(9)B Pile Driving Equipment Minimum Requirements

For each drop hammer used, the Contractor shall weigh it in the Engineer’s presence or provide the Engineer with a certificate of its weight. The exact weight shall be stamped on the hammer. Drop hammers shall weigh not less than:

1. Three thousand pounds for piles under 50 feet long that have an ultimate bearing capacity of not more than 60 tons, and
2. Four thousand pounds for piles 50 feet and longer or that have an ultimate bearing capacity of 60 to 90 tons.

If a drop hammer is used for timber piles, it is preferable to use a heavy hammer and operate with a short drop.

For each diesel, hydraulic, steam, or air-driven hammer used, the Contractor shall provide the Engineer with the manufacturer’s specifications and catalog. These shall show all data needed to calculate the developed energy of the hammer used.

Underwater hammers may be used only with approval of the Engineer.

Drop hammers on timber piles shall have a maximum drop of 10 feet. Drop hammers shall not be used to drive timber piles that have ultimate bearing capacities of more than 60 tons.

When used on timber piles, diesel, hydraulic, steam, or air-driven hammers shall provide at least 13,000 foot-pounds of developed energy per blow. The ram of any diesel hammer shall weigh at least 2,700 pounds.

Precast concrete and precast-prestressed concrete piles shall be driven with a single-acting steam, air, hydraulic, or diesel hammer with a ram weight of at least half as much as the weight of the pile, but never less than the minimums stated below. The ratio of foot-pounds to ram weight shall not exceed six. Steel casings for cast-in-place concrete, steel pipe, and steel H-piles shall also be driven with diesel, hydraulic, steam, or air hammers. These hammers shall provide at least:

1. Thirteen thousand foot-pounds of developed energy per blow (and the ram of any diesel or hydraulic hammer weighing at least 2,700 pounds) for piles with required ultimate bearing capacities not greater than 165 tons, or
2. Twenty four thousand foot-pounds of developed energy per blow (and the ram of any diesel or hydraulic hammer weighing at least 4,000 pounds) for piles with required ultimate bearing capacities not greater than 210 tons, or
3. Forty thousand foot-pounds of developed energy per blow (and the ram of any diesel or hydraulic hammer weighing at least 5,000 pounds) for piles with required ultimate bearing capacities not greater than 300 tons, or
4. Seventy thousand foot-pounds of developed energy per blow (and the ram of any diesel or hydraulic hammer weighing at least 6,500 pounds) for piles with required ultimate bearing capacities not greater than 450 tons.

These requirements for minimum hammer size may be waived if to the satisfaction of the Engineer a wave equation analysis is performed which demonstrates the ability of the hammer to obtain the required bearing capacity and minimum tip elevation without damage to the pile.

Vibratory hammers may be used to drive piles to position the piles provided the location and plumbness requirements of this section are met. The required bearing capacity for all piles driven with vibratory hammers will be determined according to 6-05.3(12) by driving the pile at least an additional 2 feet using an impact hammer. This method of determining bearing capacity will be accepted provided the blows per inch is either constant or increasing. If the pile cannot be driven 2 feet, the pile will be considered acceptable for bearing if the pile is driven to refusal.

If water jets are used, the number of jets and water volume and pressure shall be enough to erode the material next to the pile at the tip. The equipment shall include a minimum of two water-jet pipes and two 3/4-inch jet nozzles. The pump shall produce a constant pressure of at least 100 psi at each nozzle.

6-05.3(9)C Pile Driving Leads

All piles shall be driven with fixed-lead drivers. The leads shall be fixed on the top and bottom during the pile driving operation. Leads shall be long enough to eliminate the need for any follower (except for timber piles as specified in Section 6-05.3(11)E). To avoid bruising or breaking the surface of treated timber piles, the Contractor shall use spuds and chocks as little as possible. In building a trestle or foundation with inclined piles, leads shall be adapted for driving batter piles.

A driving head and pilot of the right size for the hammer shall distribute the blow and protect the top of steel piling or casings from driving damage. The driving head shall be positioned symetrically below the hammer's striking parts, so that the impact forces are applied concentric to the pile top.

For piles with specified ultimate bearing capacities of 300 tons or greater, pile driving leads other than those fixed at the top and bottom may be used to complete driving, if approved by the Engineer, when all of the following criteria are met:

1. Each plumb and battered pile is located and initially driven at least 20 feet in true alignment using fixed leads or other approved means.

2. The pile driving system (hammer, cushion and pile) will be analyzed by Pile Driving Analyzer (PDA) to verify driving stresses in the pile are not increased due to eccentric loading during driving, and transferred hammer energy is not reduced due to eccentric loading during driving, for all test piles and at least one production pile per pier. Unless otherwise specified, the cost of PDA testing shall be incidental to the various unit contract prices for driving piles.

6-05.3(10) Test Piles

If the Contract or the Engineer call for it, the Contractor shall drive test piles to determine pile lengths required to reach the required load-carrying capacity, penetration, or both. Test piles shall be:

1. Made of the same material and have the same tip diameter as the permanent piles (although test piles for treated timber piles may be either treated or untreated),
2. Driven with pile tips if the permanent piles will have tips,
3. Prebored when preboring is specified for the permanent piles,
4. Identical in cross-section and other characteristics to the permanent piles when the test piles are steel casings for cast-in-place concrete piles, precast concrete, precast-prestressed concrete or steel pipe or H-pile,
5. Long enough to accommodate any soil condition,
6. Driven with equipment and methods identical to those to be used for the permanent piles,
7. Located as the Engineer directs, and
8. Driven before permanent piles in a given pier.

Test piles may also be driven by the Contractor, (at no cost to the Contracting Agency,) as evidence that the pile driving system selected will not damage the pile or result in refusal prior to reaching any specified minimum tip elevation.

Timber test piles shall be driven outside the footing and cut off 1 foot below the finished ground line. Timber test piles shall not be used in place of permanent piles.

Steel and all types of concrete test piles shall become permanent piles. The Contracting Agency has reduced the number of permanent piles by the number of test piles.

The Contractor shall base test pile length on test-hole data in the contract. Any test piles that prove to be too short shall be replaced (or spliced if the Contract allows splicing) at the Contractor's expense.

In foundations and trestles, test piles shall be driven to at least 15 percent more than the bearing capacity required for the permanent piles, except where pile driving criteria is determined by the wave equation. When pile driving criteria is specified to be determined by the wave equation, the test piles shall be driven to the same ultimate bearing capacity as the production piles. Test piles shall penetrate at least to any minimum tip elevation specified in the Contract. If no minimum tip elevation is specified, test piles shall extend at least 10 feet below the bottom of the concrete footing or groundline, and 15 feet below the bottom of the concrete seal.

When any test pile to be left as a permanent pile has been so damaged by handling or driving that the Engineer believes it unfit for use, the Contractor shall remove and replace the pile at no additional cost to the Contracting Agency. The Engineer may direct the Contractor to overdrive the test pile to more than 15 percent above the minimum bearing capacity for permanent piles, or above ultimate bearing capacity if the wave equation is used, to determine driving criteria. In this case, the overdriving shall be at the Contractor's expense. But if pile damage results from this overdriving, any removal and replacement will be at the Contracting Agency's expense.

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6-05.3(11)A Tolerances

For elevated pier caps, the tops of piles at cut-off elevation shall be within 2 inches of the locations indicated in the Contract. For piles capped below final grade, the tops of piles at cut-off elevation shall be within 6 inches of the horizontal locations indicated in the Contract. No pile edge shall be nearer than 4 inches from the edge of any footing or cap. Piles shall be installed such that the axial alignment of the top 10 feet of the pile is within 4 percent of the specified alignment. No misaligned steel or concrete piles shall be pulled laterally. A properly aligned section shall not be spliced onto a misaligned section for any type of pile. Unless the Contract shows otherwise, all piles shall be driven vertically.

6-05.3(11)B Foundation Pit Preparation

The Contractor shall replace (and bear the cost of replacing) any pile damaged or destroyed before or during driving.

The Contractor shall completely dig all foundation pits (and build any required cofferdams or cribs) before driving foundation piles. The Contractor shall adjust pit depths to allow for upheaval caused by pile-driving, judging the amount of adjustment by the nature of the soil. Before constructing the footing or pile cap, the Contractor shall restore the pit bottom to correct elevation by removing material or by backfilling with granular material.

6-05.3(11)C Preparation for Driving

Treated and untreated timber piles shall be freshly cut square on the butt ends just before they are driven. If piles will be driven into hard material, caps, collars, or bands shall be placed on the butt ends to prevent crushing or brooming. If the head area of the pile is larger than that of the hammer face, the head shall be snipped or chamfered to fit the hammer. On treated piles, the heads shall be snipped or chamfered to at least the depth of the sapwood to avoid splitting the sapwood from the pile body.

The Contractor shall match timber pile sizes in any single bent to prevent sway braces from undue bending or distorting.

When driven, pile faces shall be turned as shown in the Plans or as the Engineer directs.

No precast-prestressed pile shall be driven until test cylinders poured with it reach at least the specified compressive strength shown in the Contract. On all other precast piles, the cylinders must reach a compressive strength of at least 4,000 psi before the piles are driven.

Pile caps of approved design shall protect the heads of all precast concrete piles as they are driven. Each pile cap shall have fitted into it a cushion next to the pile head. The bottom side of the helmet shall be recessed sufficiently to accommodate the required pile cushion and hold the pile in place during positioning and driving. The inside cap diameter shall be determined before casting the pile, and the pile head shall be formed to fit loosely inside the cap.

Steel Casing, steel pipe or H-piles shall have square-cut ends. During driving, each pile head shall be protected by a fitted metal pile cap.

6-05.3(11)D Achieving Minimum Tip Elevation and Bearing

Once pile driving has started, each pile shall be driven continuously until the required load bearing capacity shown in the contract has been achieved. Pauses during pile driving, except for splicing, mechanical breakdown, or other unforeseen events, shall not be allowed.

If the Contract specifies a minimum tip elevation, the pile shall be driven to at least the minimum tip elevation, even if the load bearing capacity has been achieved, unless the Engineer directs otherwise. If a pile does not develop the required load-bearing capacity at the minimum tip elevation, the Contractor shall continue driving the pile until the required bearing capacity is achieved. If no minimum tip elevation is specified, then the piles shall be driven to the load bearing capacity shown in the Contract and the following minimum penetrations:

Pile supporting cross-beams, bents, elevated pile caps	10 feet below final top of ground elevation
Piles supporting foundations	10 feet below bottom of foundation
Piles with a concrete seal	15 feet below bottom of seal

If overdriving is required in order to reach a specified minimum tip elevation, the Contractor shall provide a pile driving system which will not result in damage to the pile or refusal before the minimum tip elevation is reached. The cost of overdriving shall be incidental to the various unit contract prices for furnishing and driving piles.

So long as the pile is not damaged and the embankment or foundation material being driven through is not permanently damaged, the Contractor shall use normal means necessary to:

1. Secure the minimum depth specified,
2. Penetrate hard material that lies under a soft upper layer,
3. Penetrate through hard material to obtain the specified minimum tip elevation, or
4. Penetrate through a previously placed embankment.

Normal means refer to methods such as preboring, spudding, or jetting piles. Blasting or drilling through obstructions are not considered normal means.

Prebored holes and pile spuds shall have a diameter no larger than the least outside dimension of the pile. After the pile is driven, the Contractor shall fill all open spaces between the pile and the soil caused by the preboring or spudding with dry sand, pea gravel, or controlled density fill as approved by the Engineer.

If water jets are used, the jets shall be withdrawn before the pile reaches its final penetration, and the pile shall then be driven to its final penetration and bearing capacity. The pile shall be driven a minimum of 2 ft to obtain bearing after the jets are withdrawn, or to refusal, whichever occurs first. If the water jets loosen a pile previously driven, it shall be redriven in place or pulled and replaced by a new pile. To check on pile loosening, the Contractor shall attempt to redrive at least one in every five piles.

The various unit contract prices for driving piles shall cover all costs related to the use of water jets, preboring, or spudding. The Contracting Agency will not pay any costs the Contractor incurs in redriving piles loosened as a result of using water jets, preboring, or spudding.

If the Engineer requires, the Contractor shall overdrive the pile beyond the minimum load-bearing capacity and minimum tip elevation shown in the Contract. In this case, the Contractor will not be required to:

1. Use other than normal means to achieve the additional penetration;
2. Bear the expense of removing or replacing any pile damaged by overdriving; or
3. Bear the expense of overdriving the pile more than 3 feet as specified in Section 6-05.5.

In driving piles for footings with seals, the Contractor shall use no method (such as jetting or preboring) that might reduce friction capacity.

6-05.3(11)E Use of Followers for Driving

Followers shall not be used to drive concrete or steel piles. On timber piles, the Contractor may use steel (not wooden) followers if the driving head and cap fit snugly over the pile head. The Contracting Agency prefers, however, that the hammer strike the pile head directly without any cushion, block, or follower. If a follower is used, the Contractor shall, in every group of 10 piles, drive one long pile without a follower to the required bearing capacity and minimum tip elevation. This long pile shall be used to test the bearing capacity of the piles driven with a follower in the group. The tip elevation of the long pile shall be similar to the elevation of the piles driven with the follower. If the tip elevations are significantly different, as determined by the Engineer, the Contractor shall redrive the remaining piles in the group to the tip elevation of the longer pile.

6-05.3(11)F Pile Damage

The Contractor shall remove and replace (and bear the cost of doing so) any pile which is damaged as determined by the Engineer.

After driving a steel casing for a cast-in-place concrete pile, the Contractor shall leave it empty until the Engineer has inspected and approved it. The Contractor shall make available to the Engineer a light suitable for inspecting the entire length of its interior. The Engineer will reject any casing that is improperly driven, that shows partial collapse that would reduce its bearing capacity, that has been reduced in diameter, or that will not keep out water. The Contractor shall replace (and bear the cost of replacing) any rejected casing.

Pile heads which have been broomed, rolled, or otherwise significantly damaged as determined by the Engineer shall be cut back to undamaged material before proceeding with driving as well as final acceptance of the pile.

6-05.3(11)D Pile Cutoff

The Contractor shall trim the tops of all piles to the true plane shown in the Contract and to the elevation the Engineer requires. If a pile is driven below cutoff elevation without the Engineer's approval, the Contractor shall remove and replace it (and bear the costs of doing so), even if this requires a longer pile. Any pile that rises as nearby piles are driven, shall be driven down again if the Engineer requires.

Any piles under timber caps or grillages shall be sawed to the exact plane of the structure above them and fit it exactly. No shimming on top of timber piles to adjust for inaccurate pile top elevations will be permitted. If a timber pile is driven out of line, it shall be straightened without damage before it is cut off or braced.

Steel casing shall be cut off at least 6 inches below the finished ground line or at the low water line if the casing will be visible as determined by the Engineer.

6-05.3(11)F Pile Driving From or Near Adjacent Structures
The Contractor shall not drive piling from an existing structure unless all of the following conditions are met:

1. The existing structure will be demolished within the contract.
2. The existing structure is permanently closed to traffic, and
3. Working drawings are submitted in accordance with Sections 6-01.9 and 6-02.3(16), showing the structural adequacy of the existing structure to safely support all of the construction loads.

To minimize the detrimental effects of pile driving vibrations on new concrete less than 28 days old, piles shall not be driven closer to the new concrete than the distance determined from the following formula:

D = C times the square root of E

Where: D = distance in feet
E = rated hammer energy in foot-pounds
C = coefficient shown below based on the number of days of curing time

Curing Time (days)	**Coefficient (C)**	**Curing Time (days)**	**Coefficient (C)**
1	0.34	6	0.12
2	0.23	7-9	0.11
3	0.18	10-13	0.10
4	0.15	14-20	0.09
5	0.13	21-28	0.08

This distance may be reduced if approved in writing by the Engineer.

6-05.3(12) Determination of Bearing Capacities
The following formula shall be used to determine ultimate bearing capacities:

$$P = 1.5E \log 100N$$

Where: P = ultimate bearing capacity, in tons

E = developed energy, equal to W times H*, in ft-kips
W = weight of hammer striking parts, in kips
H = vertical drop of hammer or stroke of ram, in feet
N = average penetration in blows per inch for the last 4 inches of driving

*For closed-end diesel hammers (double-acting), the developed hammer energy (WH) is to be determined from the bounce chamber reading. Hammer manufacturer calibration data may be used to correlate bounce chamber pressure to developed hammer energy. For double acting hammer hydraulic and air/steam hammers, the developed hammer energy shall be calculated from ram impact velocity measurements or other means approved by the Engineer. For open ended diesel hammers (single-acting) use the blows per minute to determine the developed energy (WH).

The above formula applies only when:

1. The hammer is in good condition and operating in a satisfactory manner;
2. A follower is not used;
3. The pile top is not damaged;
4. The pile head is free from broomed or crushed wood fiber;
5. The penetration occurs at a reasonably quick, uniform rate; and the pile has been driven at least 2 feet after any interruption in driving greater than 1 hour in length.
6. There is no perceptible bounce after the blow. If a significant bounce cannot be avoided, twice the height of the bounce shall be deducted from “H” to determine its true value in the formula.
7. For timber piles, bearing capacities calculated by the formula above shall be considered effective only when it is less than the crushing strength of the piles.

The Engineer may require the Contractor to install a pressure gauge on the inboard end of the hose to check pressure at the hammer.

If water jets are used in driving, bearing capacities shall be determined either: (1) by calculating it with the driving data and the formula above after the jets have been withdrawn and the pile is driven at least 2 feet, or (2) by applying a test load.

6-05.3(13) Treatment of Timber Pile Heads

After cutting timber piles to correct elevation, the Contractor shall thoroughly coat the heads of all untreated piles with two coats of creosote oil (except concrete-encased piles).

After cutting treated timber piles to correct elevation, the Contractor shall brush three coats of creosote oil on all pile heads (except those to be covered with concrete footings or concrete caps). The pile heads shall then be capped with alternate layers of an approved roofing asphalt and a waterproofing fabric that conforms to Section 9-11.2. The cap shall be made of four layers of an approved roofing asphalt and three layers of fabric. The fabric shall be cut large enough to cover the pile top and fold down at least 6 inches along all sides of the pile. After the fabric cover is bent down over the pile, its edges shall be fastened with large-head galvanized nails or with three turns of galvanized wire. The edges of the cover shall be neatly trimmed.

On any treated timber pile encased in concrete, the cut end shall receive two coats of creosote oil and then a heavy coat of an approved roofing asphalt.

6-05.3(14) Extensions and Build-ups of Precast Concrete Piles

The Contractor shall add extensions or build-ups (if necessary) on precast concrete piles after they are driven to the required bearing capacity and minimum tip elevation.

Before adding extensions or build-ups to precast-prestressed piles, the Contractor shall remove any spalled concrete, leaving the pile fresh-headed and with a top surface perpendicular to the axis of the pile. The concrete in the build-up shall reach a minimum compressive strength of 5,000 psi at 28 days.

Before adding to non-prestressed precast concrete piles, the Contractor shall cut the pile head away to a depth 40 times the diameter of the vertical reinforcing bar. The final cut shall be perpendicular to the axis of the pile. Reinforcement of the same density and configuration as used in the pile shall be used in the build-up and shall be fastened firmly to the projecting steel. Forms shall be placed to prevent concrete from leaking along the pile. The concrete in the build-up shall reach a minimum compressive strength of 4,000 psi at 28 days.

Just before placing the concrete for extensions or build-ups to precast or precast-prestressed concrete piles, the Contractor shall thoroughly wet the top of the pile. Forms shall remain in place at least three days.

6-05.3(15) Completion of Cast-In-Place Concrete Piles

After approval by the Engineer, driven casings shall be cut off horizontally at the required elevation. They shall be clean and free of water when concrete and reinforcing steel are placed.

These piles shall consist of steel casings driven into the ground, reinforced as specified, and filled with Class 4000P concrete.

6-05.3(15)A Reinforcement

All bars shall be fastened rigidly into a single unit, then lowered into the casing before the concrete is placed. Loose bars shall not be used.

Spiral hooping reinforcement shall be deformed steel bar, plain steel bar, cold-drawn wire, or deformed wire.

6-05.3(15)B Placing Concrete

Before placing concrete, the Contractor shall remove all debris and water from the casing. If the water cannot be removed, the casing shall be removed (or cut off 2 feet below the ground and filled with sand) and a new one driven.

The Contractor shall place concrete continuously through a 5-foot rigid conduit directing the concrete down the center of the pile casing, ensuring that every part of the pile is filled and the concrete is worked around the reinforcement. The top 5 feet of concrete shall be placed with the tip of the conduit below the top of fresh concrete. The Contractor shall vibrate, as a minimum, the top 10 feet of concrete. In all cases the concrete shall be vibrated to a point at least 5 feet below the original ground line.

6-05.4 Measurement

Measurement for driving (type) pile will be the number of piles driven in place.

In these categories, measurement will be the number of linear feet driven below cutoff or as shown in the Engineer's order list:

1. Furnishing timber piling (untreated or name of treatment).
2. Precast concrete and precast-prestressed concrete piling.

In these categories, measurement will be the number of linear feet driven below cutoff, but no Engineer's order list will be provided:

1. Cast-in-place concrete piling.
2. Furnishing steel piling.

Measurement for furnishing and driving test piles will be the number actually furnished and driven as the Contract requires.

Measurement for steel pile tips or shoes will be by the number of tips or shoes actually installed and driven in place on steel casings or steel piles.

6-05.5 Payment

Payment will be made in accordance with Section 1-04.1, for each of the following bid items that are included in the proposal:

1. "Furnishing and Driving (type) Test Pile", per each.

The unit contract price per each for "Furnishing and Driving (type) Test Pile" shall be full pay for furnishing and driving test piles to the bearing capacity or penetration required by the Engineer, furnishing and installing a pile tip when pile tips are specified for the permanent piles, preboring when preboring is specified for the permanent piles, for pulling the piles or cutting them off as required, and for removing them from the site or for delivery to the Contracting Agency for salvage when ordered by the Engineer. This price shall also include all costs in connection with moving all pile driving equipment or other necessary equipment to the site of the work and for removing all such equipment from the site after the piles have been driven. If, after the test piles have been driven, it is found necessary to eliminate the piling from all or any part of the structure, no additional pay will be allowed for moving the pile driving equipment to and from the site of the work.

2. “Driving Timber Pile (untreated or name treatment)”, per each.
The unit contract price per each for “Driving Timber (type) Pile” shall include any metal shoes which the Contractor has determined to be beneficial to the pile driving.

3. “Driving Conc. Pile (size)”, per each.

4. “Driving St. Pile”, per each.
The unit contract price per each for “Driving (type) Pile (____)” shall be full pay for driving the pile to the bearing and/or penetration specified. When overdriving piles beyond the minimum bearing capacity and minimum tip elevation specified in the Contract is required by the Engineer, payment for the first 3 feet of overdriving will be included in the unit contract price for “Driving (type) Pile”. Additional penetration beyond the first 3 feet of overdriving will be paid for on the basis of force account work as covered in Section 1-09.6.

5. “Furnishing Timber Piling (untreated or name treatment)”, per linear foot.

6. “Furnishing Conc. Piling (size)”, per linear foot.

7. “Furnishing St. Piling”, per linear foot.
The unit contract price per linear foot for “Furnishing (type) Piling (____)” shall be full pay for furnishing the piling specified. Such price shall also be full pay, when measurement includes, for piling length ordered but not driven.

8. Precast Concrete Pile Buildup”, force account.
Payment for build-ups of precast or precast-prestressed concrete piles will be made on the basis of force account work as covered in Section 1-09.6. No payment will be made for build-ups or additional lengths of build-up made necessary because of damage to the piling during driving. The length of splice for precast concrete piles includes the length cut off to expose reinforcing steel for the splice. The length of splice for precast-prestressed piles includes the length in which holes are drilled and reinforcing bars are grouted.

9. “Furnishing Steel Pile Tip or Shoe (size)”, per each.